FLAW DETECTION IN DISK DRIVE USING SIGNIFICANT SAMPLES OF DATA PATTERN STORED ON DISK

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority from U.S. Provisional Application Serial No. 60/203,088, filed May 9, 2000, the disclosure of which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

The present invention relates to flaw detection in storage media, and in particular, to flaw detection in a disk in a disk drive using samples generated by reading a data pattern on the disk.

BACKGROUND OF THE INVENTION

Disk drives store information on magnetic disks. Typically, the information is stored in concentric tracks on the disk and the tracks are divided into servo sectors that store servo information and data fields that store user data. A transducer head reads from and writes to the disk. The transducer head is mounted on an actuator arm assembly that moves the transducer head radially over the disk. Accordingly, the actuator arm assembly allows the transducer head to access different tracks on the disk. The disk is rotated by a spindle motor at high speed, allowing the transducer head to access different data fields within each track on the disk.

Fig. 1 illustrates a disk drive **100** that includes a base **104** and a magnetic disk (or disks) **108** (only one of which is shown). The disk **108** is connected to the base **104** by a spindle motor (not shown) mounted within or beneath a hub **112** such that the disk **108** rotates relative to the base **104**. An actuator arm assembly **116** is connected to the base **104** by a bearing **120** and suspends a transducer head **124** at a first end. The transducer head **124** reads data from and writes data to the disk **108**. A voice coil motor **128** pivots the actuator arm assembly **116** about the bearing **120** to radially position the transducer head **124** relative to the disk **108**. By changing the radial position of the transducer head **124** relative to the disk **108**, the transducer head **124** accesses different tracks **132** on the disk **108**. The voice coil motor **128** is operated by a controller **136** that is operatively connected to a host computer (not shown). A channel **140** processes data read from the disk **108** by the transducer head **124**.

Fig. 2 illustrates the disk **108** in more detail. The tracks **132** are divided into data fields **204a-204h** and servo sectors **208a-208h**. The data fields **204a-204h** store user data and the servo sectors **208a-208h** store servo information to provide the transducer head **124** with its radial position over the disk **108**.

Although the disk **108** has a relatively small number of tracks **132**, data fields **204** and servo sectors **208**, a typical disk contains a very large number of tracks, data fields and servo sectors. For example, disks having over 30,000 tracks per inch and 120 servo sectors per track are presently available. In addition, alternate configurations of the disk **108** are possible. For example, one surface of the disk **108** can be dedicated to servo information while the other surface of the disk **108** (and any remaining disks **108** in the disk drive **100**) can exclusively store user data.

Data is stored on the disk **108** using data patterns with magnetic transitions between opposite magnetic polarities. For example, the magnetic polarity in a first direction encodes a digital 1, and the magnetic polarity in a second direction encodes a digital 0. A bit cell is the shortest length of the track **132** to which a particular magnetic

5   polarity is written. Accordingly, a magnetic transition from one bit cell to the next bit cell indicates a change from one digital character to another.

The disk **108** is formed by depositing a magnetic film on a rigid substrate. The thickness of the magnetic film must be closely controlled. Where the magnetic film is too thin, the magnetic flux density produced by a magnetic transition will be too weak.

10   The disk **108** may also contain other defects, such as scratches or pits, that degrade the magnetic flux density produced by a magnetic transition. These defects can occur during the manufacture of the disk **108** or during the assembly of the disk drive **100**.

The disk drive **100** is subject to numerous qualification tests to ensure reliable storage and retrieval of user data once delivered to an end user. Flaw scan is one such

15   qualification test. Flaw scan identifies areas of the disk **108** that may not reliably store user data. Flaw scan writes a data pattern to the data fields **204** (and any other writable areas of the disk **108**) and then reads the data pattern from the data fields **204** (and any other writable areas of the disk **108**) following assembly of the disk drive **100**. The magnetic polarity in the data pattern can alternate every bit cell to produce a 1T data

20   pattern, or every i^{th} bit cell to produce an iT data pattern where i is an integer. For instance, the magnetic polarity can alternate every two bit cells to produce a 2T data pattern (110011001100 . . .), every three bit cells to produce a 3T data pattern (111000111000 . . .) and so on.

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The transducer head **124** generates a read signal in response to reading the data pattern from the disk **108**, and the read signal includes pulses caused by the magnetic transitions in the data pattern. The isolated pulse width (PW50) is the distance between the points of intersection between an isolated pulse and a line indicating 50% of the

5   maximum amplitude of the isolated pulse. Intersymbol interference is the alteration of an isolated pulse due to linear superposition of other pulses in close proximity.

Data patterns with long periods (iT) that occupy a length of the track **132** that is greater than the PW50 of a read signal derived from the disk **108** cause the transducer head **124** to generate a read signal with greater amplitude due to decreased intersymbol

10   interference. Alternatively, data patterns with short periods that occupy a length of the track **132** that is less than the PW50 increase the likelihood of detecting a flaw or the inability of a particular length of the track **132** to produce the prescribed magnetic flux density.

The channel **140** includes a partial response maximum likelihood (PRML)

15   detector (not shown) that accurately detects the data patterns even when the user data is written on the disk **108** at high bit density and the read signal exhibits intersymbol interference. The PRML detector samples the read signal at regular time intervals and determines a code word that symbolizes a set of pulses using a statistical maximum likelihood or Viterbi process. For instance, the PRML detector detects a data pattern

20   when the PW50 contains 2.5 bits of information. Accordingly, the PRML detector allows user data to be recorded at higher density than a peak detector since the peak detector is incapable of reliably decoding pulses with intersymbol interference.

The channel **140** often uses a 2T preamble to synchronize sample times (phase) and determine signal amplitudes to adjust the gain. When the phase and gain are properly adjusted, a 2T sampled waveform in the channel **140** produces a distinctive pattern. Furthermore, flaw scan often uses a 2T data pattern because of the high magnetic transition rate, low intersymbol interference, availability in the channel **140** and unique sampled pattern it produces in the channel **140**.

Fig. 3 is a flow chart of a conventional flaw scan. The transducer head **124** writes a data pattern to the data fields **204** (step **300**) and then reads the data pattern from the data fields **204** to obtain n–1 samples (step **304**) and then a next sample (the nth sample) (step **308**). The channel **140** serially determines whether each of the previous n samples have an amplitude that is less than a threshold value (step **312**). If at least one of the previous n samples has an amplitude that is greater than the threshold value, then the channel **140** returns to step **308** to take a next sample. Otherwise, the channel **140** reports a flaw to the controller **136** (step **316**) and returns to step **308** to take a next sample.

Conventional flaw scan is susceptible to erroneously qualifying a series of bit cells where noise or some other disturbance causes one or more samples to exceed the threshold value. As a result, areas of the disk **108** that cannot reliably store user data may nonetheless be qualified. Although the disk drive **100** uses error correction code (ECC) to tolerate some errors, the storage reliability could still be compromised. Similarly, conventional flaw scan is susceptible to erroneously disqualifying a length of the track **132** that does not contain errors in the presence of a sustained noise event that causes a series of samples to fall below the threshold value. This unnecessarily reduces the storage capacity of the disk drive **100**.

Conventional flaw scan typically makes two or more passes over each surface of every disk **108** in the disk drive **100** to reduce soft errors caused by random noise and thus increase the likelihood that flaws will be detected and decrease the likelihood that false errors will be reported. However, multiple flaw scans increase manufacturing time

5 and decrease manufacturing throughput.

There is, therefore, a need for a flaw scan that detects flaws and avoids false errors with high confidence with fewer passes and is inexpensive to implement.

SUMMARY OF THE INVENTION

10 The present invention detects flaws in storage media with a higher degree of statistical confidence and thus fewer passes than conventional flaw scan techniques using existing devices such as a PRML channel.

In an embodiment, detecting flaws in a disk drive includes sampling a read signal provided by reading a data pattern from a disk to obtain samples, obtaining significant

15 samples from the samples, deriving a value from the significant samples, and reporting a flaw if a comparison between the derived value and a threshold value is unacceptable.

In another embodiment, the data pattern is an iT pattern that includes a magnetic transition every i^{th} bit cell on a track in which it is written.

In another embodiment, the significant samples are taken at times corresponding

20 to expected peak and near peak values in the read signal, which in turn correspond to magnetic transitions in the data pattern, and the significant samples each have an amplitude greater than 50% of an amplitude of an isolated pulse in the read signal.

In another embodiment, the significant samples are obtained by filtering the samples using a digital band pass filter. For example, the data pattern is a 2T data pattern and the filter has a delay operator notation of $1 - D^2 + D^4 - D^6 \ldots \pm D^{2n}$ where n is the number of samples under consideration. As another example, the data pattern is a 3T data pattern and the filter has a delay operator notation of $1 + D - D^3 - D^4 + D^6 + D^7 \ldots$ $[-/+ D^{n-1} -/+ D^n]$.

In another embodiment, the derived value is a sum, an average or an integration of the magnitudes of the significant samples, or of difference values between an optimal value and the magnitudes of the significant samples.

In another embodiment, the comparison between the derived value and the threshold value is unacceptable if the derived value is less than the threshold value.

Further advantages of the present invention will become readily apparent from the following discussion, particularly when taken together with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a top view of a conventional disk drive with the cover removed;

Fig. 2 is a diagrammatic representation of a disk;

Fig. 3 is a flow chart of a conventional flaw scan;

Fig. 4A illustrates a data pattern written to a track on the disk;

Fig. 4B illustrates magnetic transitions in the data pattern in **Fig. 4A**;

Fig. 4C illustrates a read signal provided by reading the data pattern in **Fig. 4A**;

Fig. 5 illustrates a read signal influenced by intersymbol interference and a flaw;

Fig. 6 is a flow chart of a flaw scan in accordance with the present invention; and

Fig. 7 illustrates a functional hardware diagram to implement a flaw scan in accordance with the present invention.

DETAILED DESCRIPTION

5   Fig. **4A** illustrates a data pattern written to the track **132** along a cross-sectional portion of the track **132**. The data pattern is written to bit cells **400a-400l**. The arrows in the bit cells **400** indicate the magnetic polarity of the bit cells **400**. In bit cells **400a**, **400b, 400e, 400f, 400i** and **400j** the magnetic polarity in a first direction encodes a digital 1, and in bit cells **400c, 400d, 400g, 400h, 400k** and **400l** the magnetic polarity in a

10   second direction encodes a digital 0. Thus, the data pattern is a 2T data pattern and the digital characters alternately repeat for two bit cells **400**.

Fig. **4B** illustrates the magnetic transitions in the data pattern. The bit cells **400** as magnetized by the data pattern effectively form a series of magnets **404** in the track **132**. The boundaries between the magnets **404** correspond to the boundaries between the bit

15   cells **400** containing opposite magnetic polarities. Thus, the magnetic transitions occur at the boundaries between the bit cells **400b** and **400c, 400d** and **400e, 400f** and **400g, 400h** and **400i**, and **400j** and **400k**. Furthermore, the magnetic flux produced by the magnets **404** is normal to the disk **108** at the boundaries and substantially parallel to the disk **108** away from the boundaries.

20   Fig. **4C** illustrates a read signal **408** provided by the transducer head **124** as it passes through the magnetic flux produced by the bit cells **400** and reads the data pattern from the disk **108**. The read signal **408** includes peaks **412** that correspond to the magnetic transitions and zero-crossings **416** midway between the magnetic transitions.

Fig. 5 illustrates a read signal **500** influenced by intersymbol interference and a flaw. The read signal **500** has a irregular waveform shape due to intersymbol interference. The read signal **500** includes peak **504** with optimal amplitude and peaks **508a-508e** with attenuated amplitude relative to the other peaks. Since the attenuated amplitude is significantly diminished and occurs in five peaks in a row, it is unlikely that the attenuated amplitude is due to noise. Instead, the attenuated amplitude is probably due to a flaw in the disk **108**.

Conventional flaw scan may not detect this flaw. Conventional flaw scan may require a greater number of consecutive attenuated peaks than five. Conventional flaw scan is also insensitive to slight variations in amplitude loss, and if the read signal **500** contains a particularly deeply diminished peak, illustrated as alternate peak **512**, then conventional flaw scan does not take this into consideration. Furthermore, conventional flaw scan may fail to detect a flaw if even one of the peaks **508**, illustrated as alternate peak **516**, has an amplitude greater than the threshold value.

Fig. 6 is a flow chart of a flaw scan in accordance with the present invention. The transducer head **124** writes a data pattern to the data fields **204** (step **600**) and then reads the data pattern from the data fields **204** to obtain n–1 samples (step **604**) and then a next sample (the nth sample) (step **608**).

The channel **140** filters the n samples using a digital band pass filter to obtain m significant samples from the n samples (step **612**). The significant samples are taken (sampled) at times corresponding to the expected peak and near peak values in the read signal, which in turn correspond to the magnetic transitions in the data pattern read from the disk **108**. The significant samples each have an amplitude greater than 50% of an

amplitude of an isolated pulse in the read signal. Furthermore, the significant samples each have an amplitude greater than the other samples of the n samples. Thus, the filtering passes the significant samples with the largest amplitudes and discards the other samples. For instance, the filtering passes the significant samples taken at or near the

5   peaks **412** and discards the samples taken at or near the zero-crossings **416**.

For example, the data pattern is a 2T data pattern and the filter has a delay operator notation of $1 - D^2 + D^4 - D^6 \ldots \pm D^{2n}$. As another example, the data pattern is a 3T data pattern and the filter has a delay operator notation of $1 + D - D^3 - D^4 + D^6 + D^7$. $\ldots [-/+ D^{n-1} -/+ D^n]$. In either case, the filtering inverts various samples so that the

10   significant samples have the same sign, and the significant samples are determined in accordance with the data pattern and the partial response of the channel **140**.

Advantageously, the filtering increases the signal-to-noise ratio by retaining only the peak and near peak samples taken at times corresponding to the magnetic transitions in the data pattern and discarding the other samples where noise can greatly affect the

15   signal amplitude. In particular, the filtering reduces the noise bandwidth by the square root of $1/m$ where m is the number of the significant samples that are considered. As a result, the channel **140** more accurately distinguishes flaws from noise.

The channel **140** selects a predetermined number of the previous significant samples using a moving window on a first-in first-out (FIFO) basis (step **616**) and derives

20   a value based on the selected significant samples (step **620**). As examples, the derived value is a sum, an average or an integration of the magnitudes of the significant samples, or a sum, an average or an integration of difference values between an optimal value and the magnitudes of the significant samples.

The channel 140 determines whether the derived value is less than a threshold value (step 624). If not, then the channel 140 returns to step 608 to take a next sample. Otherwise, the channel 140 reports a flaw to the controller 136 (step 628) and returns to step 608 to take a next sample.

For example, the data pattern is a 2T data pattern, m is equal to 5, the filter has a delay operator notation of $1 - D^2 + D^4 - D^6 + D^8$, the samples are quantized into integer values ranging from −30 to +30, the partial response of the channel 140 defines the optimal peak amplitude as 16, the derived value is a sum of the significant samples and the sum is 5 x 16 = 80.

The threshold value depends on the partial response of the channel 140. For example, where the read signal is quantized into integer values ranging from −30 to +30, and the optimal peak amplitude is 16, a threshold value of less than 16 is selected for comparison with an average of the absolute value of each of the previous m significant samples. Likewise, a threshold value of less than m x 16 is selected for comparison with a sum or integrated value of the absolute values of the previous m significant samples. A threshold value is about 50-90% of the accumulated value is suitable. The threshold value also depends on the size of the defects to be detected.

Fig. 7 illustrates a functional hardware diagram to implement a flaw scan in accordance with the present invention. A shift register 700 receives the significant samples from the filter (not shown) on a FIFO basis and temporarily stores the significant samples as the absolute values of their magnitudes. The shift register 700 continually feeds the significant samples to a summing block 704. The summing block 704 calculates the derived value as a sum of the significant samples and the derived value

(sum) is continually clocked to a comparator **708**. A memory **712** provides the threshold

value to the comparator **708**. The comparator **708** compares the sum with the threshold

value and sends a flaw detect signal to the controller **136** if the sum is less than the

threshold value. In this manner, the shift register **700**, the summing block **704** and the

5   comparator **708** implement steps **616**, **620**, and **624** and **628**, respectively.

Although the present invention has been described in connection with the disk

drive **100**, the present invention may be applied to any storage device such as optical,

tape and three-dimensional storage devices. Similarly, the present invention may be

implemented in the disk drive **100** as software code running on a microprocessor or as

10   firmware code running in the controller **136** and/or channel **140**. Likewise, although the

present invention has been described in connection with a longitudinal recording disk

108, the present invention is equally applicable to a perpendicular recording disk. And

although the signal-to-noise ratio can be increased by increasing the period of an iT data

pattern (at least until the effective channel bit density is one), the present invention is

15   applicable to any data pattern including a 1T data pattern.

The foregoing discussion of the invention has been presented for purposes of

illustration and description. Further, the description is not intended to limit the invention

to the form disclosed herein. Consequently, variations and modifications commensurate

with the above teachings, within the skill and knowledge of the relevant art, are within

20   the scope of the present invention. The embodiments herein are further intended to

explain the best mode presently known of practicing the invention and to enable others

skilled in the art to utilize the invention in such or in other embodiments and with various

modifications required by their particular application or use of the invention. It is

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intended that the appended claims include alternative embodiments to the extent

permitted by the prior art.